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COUPLING OF IMPLODING-PLASMA LOADS TO HIGH-POWER GENERATORS.(U)
JAN 78 D MOSHER

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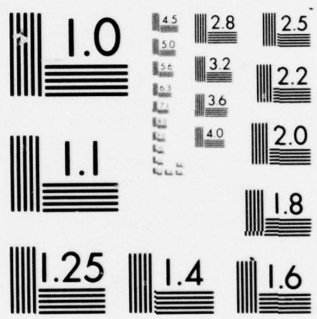

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NRL Memorandum Report 3687

Coupling of Imploding-Plasma Loads to High-Power Generators

DAVID MOSHER

Plasma Technology Branch
Plasma Physics Division

January 1978

NAVAL RESEARCH LABORATORY
Washington, D.C.

ERRATA

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Page 2, Equation (5) — The coefficient 8.43 should read 8.34.

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A simple analytic model for the implosion of annular plasma loads driven by high-power pulse line generators is presented. Tabulations of imploded-plasma parameters as a function of dimensionless variables characterizing the generator and load are presented and can be used to characterize the efficiency of energy transfer between generator and load and the final plasma state. These results are used to compare optimal load configurations for the three pulse-duration options of the Proto II accelerator.

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COUPLING OF IMPLODING-PLASMA LOADS TO HIGH-POWER GENERATORS

Numerous experiments carried out in the last few years have demonstrated the value of imploding high-Z material loads for the production of high-energy-density plasma sources[1,2]. The chief advantage of this technique is the power-multiplication capability associated with the hydrodynamics of the magnetically-driven plasma load. Kinetic energy of implosion gained during the electrical pulse is transformed to plasma internal energy on the shorter time scale associated with the axial assembly and thermalization of the imploded mass. The purpose of this report is to present the results of a simple theory for the coupling of imploding-plasma loads to transmission-line generators in a nondimensional form which allows one to specify loads to fit a wide variety of generator and assembled-plasma characteristics. Because of the general form of presented results, they can be used to: estimate optimum load characteristics for a given generator, determined the parasitic effects of diode inductance, or specify generator parameters for given assembled-plasma source requirements. The simple theory is first reviewed. This is followed by the presentation of tabulated results for a wide range of critical dimensionless parameters. Relations between these parameters corresponding to optimized loads are then presented in graphical form. Finally, predictions of the theory for imploding loads on Proto II are briefly discussed.

The generator imploding-plasma system is approximated by two coupled differential equations for the implosion dynamics and lumped-parameter-equivalent generator circuit. The equation governing the dynamics of implosion is

$$r \frac{d^2r}{dt^2} = 1\times10^{-2} I^2(t)/m \qquad (1)$$

where r is the radius of a thin, annular imploding mass in cm. The quantities $I(t)$ and m are the total current flowing through the load in amperes and the mass in grams per cm of load length. The generator is modeled by a square-wave, open-circuit-voltage pulse V_o driving the characteristic generator impedance Z_G, a fixed diode inductance L_D, and a time-varying load inductance L_W

$$V_o = Z_G I + L_D \frac{dI}{dt} + \frac{d}{dt}(L_W I) \qquad (2)$$

Note: Manuscript submitted December 27, 1977.

The radius, time, and current are now normalized according to

$$\rho = r/R_o \ ; \quad \tau = t/t_c \ ; \quad i = I/I_S \tag{3}$$

where R_o is the initial (i.e. mounting) radius of the load, t_c is a characteristic implosion time

$$t_c^2 = \frac{.834\times10^3 m R_o^2}{I_S^2} \tag{4}$$

and I_S is the short-circuit current V_o/Z_G.

In terms of the normalized variables, Eqs. (1) and (2) take the form

$$\rho \frac{d^2\rho}{d\tau^2} = 8.43 i^2 \tag{5}$$

$$i + \beta\left\{\frac{di}{d\tau} + \alpha \frac{d}{d\tau}[i\ln(1.1/\rho)]\right\} = 1 \tag{6}$$

In Eq. (6), L_W has been determined by assuming that the current-return radius is 1.1 R_o. The number of parameters associated with the generator and source have been reduced to the pair α and β by normalization. These are defined as

$$\alpha = \frac{2\times10^{-9}\ell}{L_D} \quad ; \quad \beta = \frac{L_D}{Z_G t_c} \tag{7}$$

where ℓ is the axial length of the load in cm and L_D is in henries. The new dimensionless parameters measure the ratio of load inductance to diode inductance and the ratio of L/R generator risetime to the characteristic implosion time. The instantaneous kinetic energy of the imploding mass can be determined in terms of the dimensionless variables

$$K = \frac{1}{2} m\ell\left(\frac{dr}{dt}\right)^2 = 5\times10^{-11} I_S^2 \ell \left(\frac{d\rho}{d\tau}\right)^2 \quad \text{Joules} \quad . \tag{8}$$

A figure of merit for the coupling of generator to load can now be defined as the ratio of energy delivered to a non-inductive matched

load during the implosion time to the final kinetic energy of implosion. Since

$$E_M = I_S^2 Z_G \tau_f t_c / 4$$

where τ_f is the normalized complete implosion time, the figure of merit may be written

$$\mathrm{FOM} = \frac{E_M}{K} = \frac{10\tau_f}{\alpha\beta(d\rho/d\tau)_f^2} \qquad (9)$$

and the subscript f denotes evaluation at the time of plasma assembly on axis to the final radius $r_f = a$, i.e. at the time when $\rho = \rho_f = a/R_o$. Note that improved coupling of generator to load is associated with lower values of FOM.

The six pages of Table I following the text list important parameters associated with the generator-load system as a function of α and β. Each page corresponds to a value of the implosion aspect ratio ρ_f = RF/RO. Values of ρ_f less than .05 are considered unlikely because of hydrodynamic instabilities; values in excess of .3 are uninteresting because of low values of power multiplication. The listed variables are identified with the nomenclature of this text according to

$$\mathrm{TF/TC} = \tau_f \quad ; \quad \mathrm{IF/IS} = i_f$$

$$\mathrm{VF{*}TC/RO} = (d\rho/d\tau)_f$$

The final kinetic energy of implosion can be obtained from the tables using Eq. (8) and the energy-delivery requirements of the generator can be calculated from the definition of FOM in Eq. (9). As can be seen from the tables, the efficiency of energy transfer depends sensitively on α, i.e. the ratio of load to diode inductance and is optimum (minimum FOM) for some value of $\beta = \beta_m$ dependent on α alone for the range of ρ_f values considered. Optimized values of β and FOM vs. α are shown in Fig. 1. Note that even very inductive loads are predicted to have only about 1/2 of the matched-load energy. However, this efficiency of energy transfer is model dependent in that it may be improved by voltage-pulse shaping.

It is interesting to note that although the maximum energy transfer is predicted to occur for large values of α, the maximum kinetic energy per unit mass is associated with smaller values. To see this, all quantities are kept constant except for ℓ, the length of load.

Since FOM decreases with α (and therefore ℓ) more slowly than linear, the quantity $\ell \cdot$FOM increases with α. For fixed m, the kinetic energy per nucleon goes inversely with this quantity, i.e. it decreases with α. Thus, the appropriate value of α depends not only on energy transfer but also on the application. For example, imploding-plasma neutron-production experiments would benefit from small values of α. The same would be true for any assembled plasma in which high temperatures were of prime importance. However, experiments in which it is desired to maximize thermal-energy density or total plasma energy might benefit from the higher coupling efficiency (FOM^{-1}) and larger volumes associated with larger values of α.

As an example of the application of the theory presented, consider electrical coupling to loads driven by the 20, 50, and 160 ns options for Proto II. Consideration is limited to the electrical characteristics and load geometry already discussed[3]. Parameters common to the three pulse durations in that report are $\rho_f = .05$, $R_o = 2$ cm, $\ell = 2$ cm, and $L_D = 12.8$ nh for which $\alpha = .31$, and $L_D/Z_G = 43$ ns. Parameters associated with each of the three options is shown in Table II. The run-in time t_f is taken as the nominal pulse duration with the values of β and t_c determined from Eq. (7) and the variation of τ_f with β for $\alpha = .31$. The figure of merit is then determined for the specified values of α and β. Calculation of E_m and Eq. (9) are then used to determine the kinetic energy of implosion. The load mass/cm is then calculated from the definition of t_c and the values of R_o and I_s. The table shows that the best match of the specified load geometry to the generator is provided by the 50 ns option. The 20 ns pulse is too short to efficiently accelerate loads because of the large relative L/R generator risetime, while the short-circuit current of the 160 ns option is too low to efficiently drive even a matched load. Although the matched energy calculated here for a 50 ns pulse is similar to that previously determined[3], the energy coupled to the load is determined to be about double that previously calculated. This is primarily due to a factor-of-four lower mass as shown in Table II for the optimized case. The desirability of lower mass can be understood in terms of the factor-of-two more-rapid collapse time associated with it. The acceleration at small radii is then increased because of the higher current flowing through the load. From the tables, the final current is seen to be about 2 MA for the present case while the higher-mass-load calculation resulted[3] in a value of .8 MA. Detailed comparison of the two calculations is difficult however, because of the different assumed open-circuit wave forms.

The predicted optimum mass for the 50 ns option is too low for practical mounting of annular foils (corresponding to a foil thickness of about 1 $\mu g/cm^2$). However, from the definition of t_c, it is seen that $m \sim R_o^{-2}$ so that the foil thickness $\rho x \sim R_o^{-3}$. The load may therefore be optimized by reducing the mounting radius to approximately 1 cm, thus permitting foils in the 5-10 $\mu g/cm^2$ to be mounted.

The calculated implosion energies have at least two major sources of error. The first is that compression-ratios of 20 to 1 assumed here are probably over estimates in light of experiments carried out using similar generators[1]. The choice $\rho_f = .05$ was made in order to more-readily compare present results with those previously obtained using a similar model. A more conservative value of coupled energy may be obtained using ρ_f in the range .1 - .15. Secondly, the square-wave voltage waveform assumed here is not realistic. However, it is not now known whether the actual open-circuit waveforms for Proto II (50) improve or reduce coupling efficiency to optimized loads. Finally, it should be noted that greater energy coupling is predicted by Fig. 1 if the length of the load is increased beyond the 2 cm currently envisioned. This is especially important if the diode inductance greatly exceeds the 12.8 nh value used in the current calculations.

ACKNOWLEDGEMENT

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Table 1a

Implosion assembly parameters vs. α and β for ρ_f = .05

****** RF/R0=.05 ******

ALPHA	BETA	TF/TC	IF/IS	VF*TC/R0	FOM
0.10000	0.10000	0.56600	0.84121	-6.40737	13.78659
0.10000	0.20000	0.67565	0.79085	-6.00325	9.37386
0.10000	0.40000	0.84795	0.70405	-5.29419	7.56331
0.10000	0.80000	1.10485	0.58967	-4.39569	7.14760
0.10000	1.60000	1.47725	0.47010	-3.47913	7.62771
0.10000	3.20000	2.01015	0.36132	-2.66394	8.85179
0.20000	0.10000	0.57225	0.73904	-6.04326	7.83453
0.20000	0.20000	0.68455	0.67961	-5.57483	5.50657
0.20000	0.40000	0.86025	0.59580	-4.85336	4.56509
0.20000	0.80000	1.12185	0.49380	-4.00043	4.38128
0.20000	1.60000	1.50075	0.39108	-3.15168	4.72146
0.20000	3.20000	2.04255	0.29959	-2.40227	5.53030
0.40000	0.10000	0.58375	0.61159	-5.50905	4.80853
0.40000	0.20000	0.70115	0.54444	-4.96906	3.54955
0.40000	0.40000	0.88355	0.46555	-4.25631	3.04821
0.40000	0.80000	1.15395	0.38014	-3.46264	3.00761
0.40000	1.60000	1.54515	0.29784	-2.70536	3.29869
0.40000	3.20000	2.10425	0.22655	-2.05172	3.90527
0.80000	0.10000	0.60455	0.47857	-4.83675	3.23024
0.80000	0.20000	0.73135	0.40909	-4.24459	2.53708
0.80000	0.40000	0.92585	0.33929	-3.55114	2.29432
0.80000	0.80000	1.21275	0.27066	-2.84206	2.34598
0.80000	1.60000	1.62675	0.20902	-2.19549	2.63663
0.80000	3.20000	2.21785	0.15743	-1.65244	3.17280
1.60000	0.10000	0.64095	0.35939	-4.09976	2.38334
1.60000	0.20000	0.78395	0.29478	-3.48206	2.02053
1.60000	0.40000	1.00015	0.23558	-2.83884	1.93911
1.60000	0.80000	1.31645	0.18331	-2.22849	2.07098
1.60000	1.60000	1.77125	0.13916	-1.69809	2.39948
1.60000	3.20000	2.41975	0.10352	-1.26632	2.94723
3.20000	0.10000	0.70195	0.26389	-3.36482	1.93746
3.20000	0.20000	0.87205	0.20832	-2.76474	1.78259
3.20000	0.40000	1.12485	0.16118	-2.19394	1.82573
3.20000	0.80000	1.49145	0.12236	-1.68810	2.04444
3.20000	1.60000	2.01655	0.09117	-1.26844	2.44795
3.20000	3.20000	2.76374	0.06696	-0.93656	3.07698

Table 1b

Implosion assembly parameters vs. α and β for ρ_f = .07

****** RF/R0=.07 ******

ALPHA	BETA	TF/TC	IF/IS	VF*TC/R0	FOM
0.10000	0.10000	0.56295	0.86059	-6.10538	15.10233
0.10000	0.20000	0.67225	0.81013	-5.70735	10.31886
0.10000	0.40000	0.84405	0.72137	-5.02329	8.36242
0.10000	0.80000	1.10015	0.60415	-4.16683	7.92047
0.10000	1.60000	1.47135	0.48139	-3.29631	8.46333
0.10000	3.20000	2.00245	0.36988	-2.52194	9.83880
0.20000	0.10000	0.56885	0.76788	-5.78079	8.51126
0.20000	0.20000	0.68085	0.70729	-5.33129	5.98861
0.20000	0.40000	0.85605	0.62029	-4.64248	4.96488
0.20000	0.80000	1.11675	0.51407	-3.82268	4.77640
0.20000	1.60000	1.49425	0.40702	-3.00866	5.15854
0.20000	3.20000	2.03405	0.31164	-2.29260	6.04682
0.40000	0.10000	0.58005	0.64626	-5.30821	5.14646
0.40000	0.20000	0.69705	0.57687	-4.79266	3.79333
0.40000	0.40000	0.87875	0.49383	-4.10447	3.26010
0.40000	0.80000	1.14805	0.40316	-3.33780	3.22027
0.40000	1.60000	1.53765	0.31578	-2.60747	3.53378
0.40000	3.20000	2.09435	0.24016	-1.97681	4.18707
0.80000	0.10000	0.60035	0.51404	-4.69507	3.40432
0.80000	0.20000	0.72655	0.44058	-4.12485	2.66888
0.80000	0.40000	0.92015	0.36565	-3.45335	2.41117
0.80000	0.80000	1.20565	0.29189	-2.76439	2.46514
0.80000	1.60000	1.61755	0.22546	-2.13527	2.77167
0.80000	3.20000	2.20565	0.16978	-1.60700	3.33629
1.60000	0.10000	0.63605	0.39067	-4.00467	2.47878
1.60000	0.20000	0.77815	0.32129	-3.40599	2.09618
1.60000	0.40000	0.99305	0.25717	-2.77898	2.00918
1.60000	0.80000	1.30735	0.20029	-2.18194	2.14534
1.60000	1.60000	1.75945	0.15195	-1.66330	2.48425
1.60000	3.20000	2.40385	0.11308	-1.24031	3.05195
3.20000	0.10000	0.69595	0.28932	-3.30113	1.99573
3.20000	0.20000	0.86475	0.22886	-2.71640	1.83115
3.20000	0.40000	1.11565	0.17730	-2.15727	1.87288
3.20000	0.80000	1.47955	0.13462	-1.66075	2.09547
3.20000	1.60000	2.00065	0.10037	-1.24811	2.50839
3.20000	3.20000	2.74224	0.07372	-0.92171	3.15226

Table 1c

Implosion assembly parameters vs. α and β for $\rho_f = .1$

****** RF/R0=.10 ******

ALPHA	BETA	TF/TC	IF/IS	VF*TC/R0	FOM
0.10000	0.10000	0.55785	0.88130	-5.73097	16.98483
0.10000	0.20000	0.66685	0.83036	-5.35577	11.62395
0.10000	0.40000	0.83795	0.73933	-4.70799	9.45121
0.10000	0.80000	1.09275	0.61899	-3.89725	8.99322
0.10000	1.60000	1.46195	0.49304	-3.07839	9.64194
0.10000	3.20000	1.99015	0.37873	-2.35296	11.23334
0.20000	0.10000	0.56355	0.79853	-5.46620	9.43041
0.20000	0.20000	0.67505	0.73741	-5.03840	6.64800
0.20000	0.40000	0.84945	0.64676	-4.38452	5.52337
0.20000	0.80000	1.10865	0.53629	-3.60423	5.33396
0.20000	1.60000	1.48395	0.42455	-2.83422	5.77302
0.20000	3.20000	2.02065	0.32485	-2.15928	6.77162
0.40000	0.10000	0.57425	0.68534	-5.05808	5.61137
0.40000	0.20000	0.69065	0.61367	-4.57180	4.13042
0.40000	0.40000	0.87125	0.52624	-3.91412	3.55431
0.40000	0.80000	1.13885	0.42967	-3.18167	3.51566
0.40000	1.60000	1.52585	0.33669	-2.48406	3.86374
0.40000	3.20000	2.07875	0.25607	-1.88232	4.58358
0.80000	0.10000	0.59385	0.55540	-4.51406	3.64293
0.80000	0.20000	0.71915	0.47805	-3.97233	2.84846
0.80000	0.40000	0.91135	0.39736	-3.32793	2.57150
0.80000	0.80000	1.19465	0.31754	-2.66407	2.63008
0.80000	1.60000	1.60325	0.24544	-2.05726	2.95947
0.80000	3.20000	2.18665	0.18486	-1.54810	3.56402
1.60000	0.10000	0.62845	0.42871	-3.87957	2.60966
1.60000	0.20000	0.76925	0.35373	-3.30645	2.19884
1.60000	0.40000	0.98205	0.28407	-2.69972	2.10531
1.60000	0.80000	1.29345	0.22134	-2.12113	2.24597
1.60000	1.60000	1.74115	0.16810	-1.61708	2.60095
1.60000	3.20000	2.37925	0.12517	-1.20588	3.19569
3.20000	0.10000	0.68675	0.32086	-3.21697	2.07374
3.20000	0.20000	0.85365	0.25446	-2.65268	1.89553
3.20000	0.40000	1.10155	0.19774	-2.10847	1.93579
3.20000	0.80000	1.46125	0.15029	-1.62416	2.16386
3.20000	1.60000	1.97635	0.11211	-1.22108	2.58886
3.20000	3.20000	2.70934	0.08239	-0.90191	3.25262

Table 1d

Implosion assembly parameters vs. α and β for ρ_f = .15

****** RF/R0=.15 ******

ALPHA	BETA	TF/TC	IF/IS	VF*TC/R0	FOM
0.10000	0.10000	0.54875	0.90381	-5.25016	19.90806
0.10000	0.20000	0.65715	0.85257	-4.89820	13.69501
0.10000	0.40000	0.82685	0.75905	-4.29241	11.21924
0.10000	0.80000	1.07935	0.63500	-3.54526	10.73435
0.10000	1.60000	1.44495	0.50544	-2.79511	11.55938
0.10000	3.20000	1.96785	0.38806	-2.13312	13.51489
0.20000	0.10000	0.55405	0.83355	-5.04483	10.88495
0.20000	0.20000	0.66475	0.77194	-4.64746	7.69427
0.20000	0.40000	0.83755	0.67788	-4.03603	6.42704
0.20000	0.80000	1.09425	0.56194	-3.31353	6.22897
0.20000	1.60000	1.46555	0.44480	-2.60125	6.76839
0.20000	3.20000	1.99645	0.34027	-1.97952	7.96082
0.40000	0.10000	0.56405	0.73206	-4.71649	6.33897
0.40000	0.20000	0.67935	0.65874	-4.26633	4.66547
0.40000	0.40000	0.85805	0.56610	-3.65073	4.02376
0.40000	0.80000	1.12265	0.46256	-2.96564	3.98895
0.40000	1.60000	1.50495	0.36274	-2.31248	4.39732
0.40000	3.20000	2.05125	0.27581	-1.75161	5.22318
0.80000	0.10000	0.58255	0.60751	-4.25865	4.01513
0.80000	0.20000	0.70625	0.52631	-3.75433	3.13166
0.80000	0.40000	0.89595	0.43903	-3.14730	2.82655
0.80000	0.80000	1.17535	0.35154	-2.51898	2.89426
0.80000	1.60000	1.57825	0.27195	-1.94486	3.25979
0.80000	3.20000	2.15345	0.20490	-1.46326	3.92875
1.60000	0.10000	0.61525	0.47923	-3.69730	2.81295
1.60000	0.20000	0.75375	0.39795	-3.15965	2.35940
1.60000	0.40000	0.96315	0.32067	-2.58372	2.25436
1.60000	0.80000	1.26935	0.25048	-2.03100	2.40410
1.60000	1.60000	1.70955	0.19047	-1.54878	2.78396
1.60000	3.20000	2.33695	0.14189	-1.15515	3.42058
3.20000	0.10000	0.67085	0.36418	-3.09189	2.19295
3.20000	0.20000	0.83445	0.29032	-2.55698	1.99419
3.20000	0.40000	1.07745	0.22635	-2.03570	2.03123
3.20000	0.80000	1.42995	0.17245	-1.56940	2.26785
3.20000	1.60000	1.93475	0.12881	-1.18050	2.71157
3.20000	3.20000	2.65294	0.09477	-0.87215	3.40603

Table 1e

Implosion assembly parameters vs. α and β for ρ_f = .2

****** RF/R0=.20 ******

ALPHA	BETA	TF/TC	IF/IS	VF*TC/R0	FOM
0.10000	0.10000	0.53895	0.91884	-4.86381	22.78217
0.10000	0.20000	0.64645	0.86766	-4.52216	15.80567
0.10000	0.40000	0.81475	0.77187	-3.95506	13.02139
0.10000	0.80000	1.06465	0.64515	-3.25839	12.53459
0.10000	1.60000	1.42635	0.51305	-2.56512	13.54849
0.10000	3.20000	1.94335	0.39368	-1.95445	15.89832
0.20000	0.10000	0.54375	0.85826	-4.69485	12.33463
0.20000	0.20000	0.65365	0.79653	-4.32306	8.74387
0.20000	0.40000	0.82475	0.69980	-3.74703	7.34276
0.20000	0.80000	1.07855	0.58008	-3.06938	7.15518
0.20000	1.60000	1.44565	0.45888	-2.40737	7.79525
0.20000	3.20000	1.97015	0.35096	-1.82946	9.19758
0.40000	0.10000	0.55315	0.76661	-4.42536	7.06130
0.40000	0.20000	0.66725	0.69286	-4.[illegible]45	5.20390
0.40000	0.40000	0.84395	0.59642	-3.42375	4.49979
0.40000	0.80000	1.10525	0.48771	-2.77817	4.47501
0.40000	1.60000	1.48265	0.38249	-2.16463	4.94414
0.40000	3.20000	2.02175	0.29085	-1.63839	5.88410
0.80000	0.10000	0.57045	0.64874	-4.03114	4.38805
0.80000	0.20000	0.69255	0.56517	-3.55975	3.41581
0.80000	0.40000	0.87965	0.47286	-2.98553	3.08402
0.80000	0.80000	1.15495	0.37925	-2.38890	3.16219
0.80000	1.60000	1.55185	0.29358	-1.84400	3.56549
0.80000	3.20000	2.11835	0.22130	-1.38699	4.30138
1.60000	0.10000	0.60145	0.52051	-3.53279	3.01193
1.60000	0.20000	0.73765	0.43480	-3.02644	2.51674
1.60000	0.40000	0.94335	0.35187	-2.47680	2.40277
1.60000	0.80000	1.24425	0.27537	-1.94806	2.56150
1.60000	1.60000	1.67655	0.20971	-1.48561	2.96733
1.60000	3.20000	2.29274	0.15633	-1.10815	3.64663
3.20000	0.10000	0.65445	0.40070	-2.97739	2.30703
3.20000	0.20000	0.81455	0.32139	-2.46804	2.08946
3.20000	0.40000	1.05245	0.25150	-1.96752	2.12400
3.20000	0.80000	1.39755	0.19204	-1.51798	2.36918
3.20000	1.60000	1.89175	0.14363	-1.14235	2.83139
3.20000	3.20000	2.59464	0.10579	-0.84411	3.55614

Table 1f
Implosion assembly parameters vs. α and β for ρ_f = .3

****** RF/R0=.30 ******

ALPHA	BETA	TF/TC	IF/IS	VF*TC/R0	FOM
0.10000	0.10000	0.51685	0.93854	-4.22553	28.94683
0.10000	0.20000	0.62275	0.88621	-3.91203	20.34607
0.10000	0.40000	0.78745	0.78658	-3.39913	17.03833
0.10000	0.80000	1.03145	0.65566	-2.78689	16.60044
0.10000	1.60000	1.38405	0.52028	-2.18574	18.10649
0.10000	3.20000	1.88785	0.39860	-1.66163	21.36739
0.20000	0.10000	0.52105	0.89173	-4.11266	15.40295
0.20000	0.20000	0.62895	0.83009	-3.77500	11.03375
0.20000	0.40000	0.79615	0.72907	-3.25699	9.38153
0.20000	0.80000	1.04355	0.60352	-2.65751	9.23516
0.20000	1.60000	1.40085	0.47681	-2.07757	10.14215
0.20000	3.20000	1.91125	0.36425	-1.57600	12.02339
0.40000	0.10000	0.52915	0.81674	-3.92050	8.60668
0.40000	0.20000	0.64075	0.74293	-3.54507	6.37308
0.40000	0.40000	0.81295	0.64108	-3.02482	5.55323
0.40000	0.80000	1.06695	0.52453	-2.44313	5.56322
0.40000	1.60000	1.43345	0.41127	-1.90378	6.17974
0.40000	3.20000	1.95665	0.31265	-1.43875	7.38472
0.80000	0.10000	0.54435	0.71213	-3.62535	5.17713
0.80000	0.20000	0.66305	0.62651	-3.20785	4.02715
0.80000	0.40000	0.84435	0.52707	-2.68886	3.64952
0.80000	0.80000	1.11085	0.42373	-2.14985	3.75544
0.80000	1.60000	1.49475	0.32836	-1.65819	4.24706
0.80000	3.20000	2.04225	0.24772	-1.24609	5.13773
1.60000	0.10000	0.57185	0.58848	-3.22702	3.43209
1.60000	0.20000	0.70315	0.49729	-2.77469	2.85410
1.60000	0.40000	0.90135	0.40508	-2.27463	2.72202
1.60000	0.80000	1.19075	0.31838	-1.78954	2.90488
1.60000	1.60000	1.60645	0.24298	-1.36488	3.36850
1.60000	3.20000	2.19864	0.18141	-1.01792	4.14437
3.20000	0.10000	0.61955	0.46397	-2.75831	2.54472
3.20000	0.20000	0.77255	0.37626	-2.29644	2.28895
3.20000	0.40000	0.99995	0.29647	-1.83520	2.31955
3.20000	0.80000	1.32945	0.22744	-1.41742	2.58484
3.20000	1.60000	1.80125	0.17062	-1.06732	3.08825
3.20000	3.20000	2.47224	0.12588	-0.78897	3.87853

Table 2

Electrical and implosion parameters for the three pulse-duration options of the Proto II accelerator assuming ρ_f = .05, R_o = 2 cm, ℓ = 2 cm, and L_D = 12.8 nh

	I_S(MA)	t_f(ns)	β	t_c(ns)	FOM	E_M(kJ)	K(kJ)	m(g/cm)
PII(20)	6.67	20	.19	7.8	5.0	67	13	8×10^{-7}
PII(50)	5.00	50	1.1	40	3.5	94	27	1×10^{-5}
PII(160)	1.37	160	6.0	230	4.2	22	5	3×10^{-5}

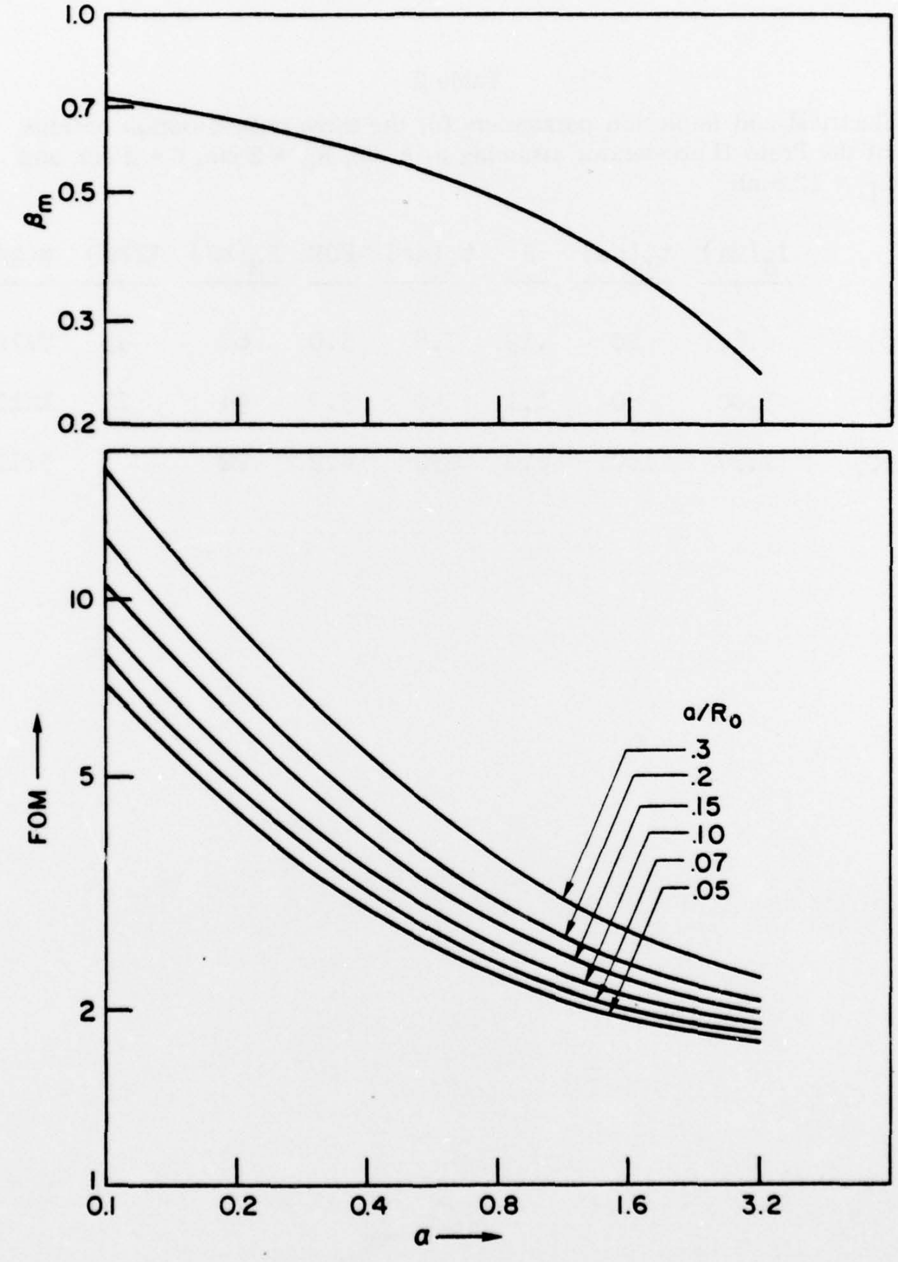

Fig. 1 — Optimized β and figure-of-merit values vs. a for various values of ρ_f

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